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EFFECT OF TEMPERATURE ELEVATION AND ENTRAINMENT ON HETEROTROPHIC UPTAKE OF ^{14}C-U-GLUTAMIC ACID

Report No 82-292-K

T.G. Dunstall
Biologist - Entrainment
Biological Research Section
Chemical Research Department

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ABSTRACT

The effect of temperature elevation and station passage on the heterotrophic uptake of glutamate in condenser cooling water was investigated at three Ontario Hydro generating stations. Glutamate uptake increased approximately 1.9 times with a 10°C rise in lakewater temperature providing the total (discharge) temperature did not exceed 30°C. Above 30°C inhibition of bacterioplankton activity was observed. Mechanical stress encountered during station passage resulted in a reduction of heterotrophic activity of approximately 57%. Temperature elevation and mechanical stress experienced during the once-through cooling process could be expected to result in a net increase in heterotrophic productivity, largely in peripheral areas of the effluent thermal plume and contiguous waters.

job	file	date	report no.
740634-555-092	837.313	July 30, 1982	82-292-K

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To Mr. F.J. Kee
Director of Research

EFFECT OF TEMPERATURE ELEVATION AND ENTRAINMENT ON HETEROTROPHIC UPTAKE OF ^{14}C-U-GLUTAMIC ACID

T.G. Dunstall

INTRODUCTION

Aquatic bacteria function in the mobilization of nutrients through detrital pathways and therefore are an important component of total energy transfer in aquatic systems (Kuznetov 1968). Mineralization rates of organic compounds in natural waters may be altered by the passage of heterotrophic microbes through cooling systems used at thermal electric generating stations. Organisms present in condenser cooling waters are subjected to abrasion, turbulence, pressure changes, elevated temperatures and occasionally to chemical biocides. Duration of exposure to elevated temperature depends upon the time elapsed prior to complete mixing of station effluent water with the receiving water body. Less severe temperature conditions are encountered by organisms entrained into the effluent thermal plume.

Densities of selected groups of bacteria in cooling water samples collected prior to and following station passage have been determined by plate count methods using a variety of nutrient enrichment media. In some instances little or no change in densities or composition was evident (Wiersma et al 1974; Lauer et al 1972; Buck and Rankin 1972) while in other studies higher densities were frequently observed in discharged cooling waters (Fox and Moyer 1973; Hamilton et al 1970; Verstraete et al 1975). Extreme reductions in viable bacteria has been observed only during periods of condenser chlorination (Hamilton et al 1970; Wiersma et al 1974; Wood 1980; Ontario Hydro Research Division Report 78-217-K).

At the James Stuart Station on the Ohio River (Miller et al 1976) and at the Crystal River Plant on the Gulf of Mexico (Fox and Moyer 1973) bacterial densities increased during discharge channel transit prior to re-entering the source water bodies. Lauer et al (1972) suggested that an increase in the number of bacteria following entrainment could be related to the length of exposure to elevated temperature relative to generation times of the organisms, providing temperature tolerance levels are not exceeded. In some instances the extent to which the increase in bacterial numbers in discharge waters was related to growth has been uncertain. Densities of bacteria may have been affected by the sloughing

or resuspension of attached bacteria induced by water turbulence (Verstraete et al 1975; Miller et al 1976).

The presence of viable bacteria following station passage does not imply that metabolic activity of the organisms has remained unchanged. The relative physiological state of heterotrophic populations under conditions experienced during entrainment was determined at the James Stuart Station by measuring the ability to utilize organic carbon supplied as ^{14}C-glucose (Miller et al 1976). The maximum uptake velocity for glucose generally occurred at temperatures elevated above ambient levels to total temperatures of 20 to 25°C. Increases of 15 to 20°C were stimulatory only if the initial ambient temperature was low. Heterotrophic potential of the microbial populations decreased through the length of the discharge channel, approaching the assimilative capacity of the organisms prior to station passage.

The physiological response of heterotrophic microbes to entrainment was also investigated at several Ontario Hydro generating stations during 1976-7 using the substrate ^{14}C-glutamate (Ontario Hydro Research Division Reports 76-489-K, 78-212-K). In this report the effects of temperature elevation and condenser passage on heterotrophic activity is summarized and an estimate of the impact of once-through cooling on microbial mineralization is presented.

STUDY SITES

Studies were conducted at three Ontario Hydro generating stations located on the lower Laurentian Great Lakes (Figure 1). Pickering GS 'A' (Lake Ontario) and Bruce GS 'A' (Lake Huron) each consist of four nuclear (CANDU) reactors with station capacity ratings of 2160 and 3000 MW respectively. The coal fired Nanticoke (Lake Erie) station, with eight units, has a capacity rating of 4000 MW.

The Pickering station obtains cooling water through a surface intake channel while at Bruce and Nanticoke water is withdrawn from offshore submerged intakes located at approximately the 11 m depth. At each station the condenser units are supplied with water from a common forebay and the discharge of water is through a common conduit leading either directly to the lake (Pickering) or into a short effluent canal prior to lake entry (Bruce, Nanticoke). At Nanticoke tempering water is mixed with condenser cooling water prior to its discharge to the lake to reduce the temperature of the effluent. Chlorine has not been used for the control of condenser biofouling at the three stations studied.

MATERIALS AND METHODS

Heterotrophic assimilation of high specific activity L-[U-^{14}C] glutamic acid (270 mCi/mmol) was measured using the substrate dilution technique described by Wright and Hobbie (1965, 1966). Samples were collected from the intake forebay and immediate discharge of the stations. A two by two factorial experimental design in which samples were incubated at forebay and discharge

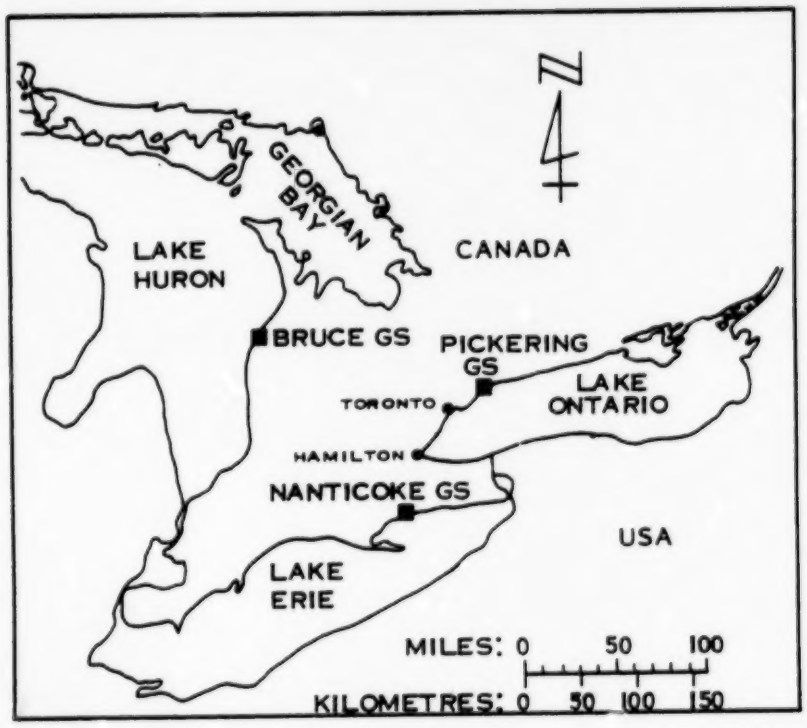

FIGURE 1

LOCATION OF ONTARIO HYDRO GENERATING STATIONS AT WHICH EXPERIMENTS WERE CONDUCTED

temperature enabled discrimination of the separate and interactive effects of mechanical stress and temperature increase on heterotrophic activity. Forebay samples incubated at forebay temperature (FFT) represented conditions in natural lakewater while incubation at discharge temperature (FDT) represented temperature conditions encountered during entrainment. Heterotrophic activity in discharge samples incubated at discharge temperature (DDT) indicated the net effect of mechanical stress and temperature elevation. Discharge samples incubated at forebay temperature (DFT) were representative of the mechanical effects of entrainment following the return of organisms to ambient conditions.

Immediately following sample collection replicate 125 ml glass stoppered reagent bottles containing forebay and discharge water were divided between two constant temperature water baths and were slowly rotated about the vertical axis during incubation. Although the baths were maintained as close as possible to forebay and discharge temperatures the transit of water in the supply system for the incubator resulted in an increase in ambient (forebay) temperature of 1.0 to 25.°C. A summary of experimental temperature conditions is presented in Table 1.

Following a half hour adaptation period to incubation temperatures glutamic acid in concentrations of approximately 4, 8 and 16 $\mu g.L^{-1}$ was added to sets of triplicate bottles. Immediately upon addition of labelled substrate to the sample bottles, triplicate 1 mL aliquots were removed for the determination of radioactivity. Exact substrate concentration for each bottle was calculated from these 0 time values, after correction to absolute activity (dpm's). Samples were incubated in complete darkness for a period of one to two hours which varied by less than 10 min in any given experiment. Following incubation, triplicate 20 mL (1976) or 15 mL (1977) aliquots from each bottle were filtered on HAWP 0.45 µm Millipore$^{(R)}$ filters. Samples were dissolved in PCS scintillator (Amersham Searle) and radioactivity determined in an Amersham Searle Mark III liquid scintillation counter. Over the course of the study the coefficient of variation for replicate samples averaged 7.6%.

Samples of forebay water, heated to 95°C and incubated at the temperature of the discharge were used to measure abiotic absorption of labelled glutamate. There was no increase in radioactivity of control filters during the 1-2 L incubation periods. Net uptake (less respiration) of glutamic acid by the microbial populations was corrected for abiotic absorption.

Parameters describing uptake kinetics complying with the Michaelis-Menten analysis were derived using the linear transformation

$$v = V_{max} - K_t \ (v/C_s) \qquad (1)$$

where v is the substrate uptake velocity ($\mu g \cdot L^{-1} \cdot h^{-1}$) and C_s is the added substrate concentration ($\mu g \cdot L^{-1}$) (Dowd and Riggs 1965). The slope of the line in an Eadie-Hofstee plot of v against v/C_s

TABLE 1

Summary of Temperature Conditions for Heterotrophy Experiments

Location	Period	No.of Experiments	INCUBATION TEMPERATURE (°C) Ambient	ΔT	Discharge
Pickering GS'A' Lake Ontario	June 9-Nov.23 1976-7	10	7.0-18.0	6.5-11.5	16.5-28.0
Nanticoke GS Lake Erie	July 14-Nov.16 1977	4	9.5-22.0	9.0-12.5	20.5-32.5
Bruce GS 'A" Lake Huron	July 6-Nov.30 1977	4	6.0-21.0	3.0- 8.0	10.5-24.0

represents the transport constant, K_t ($\mu g \cdot L^{-1}$), a measure of the sensitivity of the population to the substrate (Hamilton and Austin 1967). The y-intercept represents the maximum uptake velocity (V_{max}) while the x-intercept gives the reciprocal of substrate turnover time (ie: $T_t = C_s/v$).

RESULTS AND DISCUSSION

Michaelis-Menten Kinetic Parameters

Comparison of Michaelis-Menten kinetic parameters for the four sample locations/incubation temperatures tested within dates was possible for the July 28 and September 21, 1976, Pickering studies only (Table 2). A general pattern was apparent, however, in which glutamate uptake was greatest in forebay samples incubated at discharge temperatures (FDT), lowest in discharge samples incubated at forebay temperatures (DFT), with values in the remaining two treatments (FFT and DDT) being intermediate. This pattern was exemplified by the two "complete" Pickering experiments shown in Figure 2.

Actual glutamate uptake velocities (V_{max}) would be higher than the values for net (cellular) uptake given in Table 2 since respiration may account for a substantial portion of total assimilated organic carbon (Hobbie and Crawford 1969). Burnison and Morita (1974) found that 63% of the glutamate removed by heterotrophic populations in an Oregon lake was respired. It is also conceivable that there is a proportional increase in respiration under conditions of thermal and/or mechanical stress.

Quantification of Mechanical and Thermal Effects of Entrainment

To enable greater use and interpretation of the experimental data (Appendix) uptake velocities at each of the three added substrate concentrations were compared between treatments. An analytical model was formulated based on the premise that the mechanical effects of condenser passage resulted in a consistent reduction in glutamate uptake while temperature elevation stimulated uptake. It was expected that an approximate doubling of heterotrophic activity would occur with a 10°C rise in temperature. The model to be evaluated was

$$G_{i,j,k} = \mu_i \cdot P^d \cdot e^{\beta_0 \Delta T + \beta_1 (d \Delta T)} \cdot C_8^{\alpha_8} \cdot C_{16}^{\alpha_{16}} \qquad (2)$$

where $G_{i,j,k}$ represents glutamate uptake ($\mu g \cdot m^{-3} \cdot h^{-1} \cdot \mu g^{-1}$ glutamate) for experiment i (i = 1 to 18), under condition j (FFT, FDT, DFT, DDT) and added glutamate concentration k(4, 8, 16 $\mu g \cdot L^{-1}$). The actual uptake of glutamate in natural lakewater samples (FFT) at an added substrate concentration of 4 $\mu g \cdot L^{-1}$ was denoted by μ_i.

The effect of condenser passage is represented by P with the exponent d equal to zero for forebay samples and equal to one for discharge samples. The effect of a 1°C increase in temperature on glutamate uptake is represented by β_0 while ΔT is the difference between sample temperature and forebay (ambient) temperature.

TABLE 2

KINETIC PARAMETERS
FOR THE HETEROTROPHIC UPTAKE OF ^{14}C-U-GLUTAMIC ACID

Station	Date	Treatment	V_{MAX} (ug L^{-1} h^{-1})	K_t (ug L^{-1})	T_t (Hours)	Correlation Coefficient	F-Value ($p < 0.05$)
Pickering	July 15/76	FFT	0.0190	2.58	135.9	- 0.890	18.95
	July 28/76	FFT	0.1434	7.80	54.4	- 0.840	16.89
		FDT	0.3364	14.15	42.1	- 0.939	52.73
		DFT	0.1091	10.33	94.7	- 0.826	15.14
		DDT	0.2178	17.52	80.4	- 0.867	21.27
	Aug 12/76	FFT	0.1662	7.87	47.4	- 0.857	19.39
		DDT	0.0799	4.57	57.2	- 0.850	18.29
	Sept 3/76	FFT	0.1088	5.72	52.6	- 0.908	33.05
		FDT	0.1987	9.98	50.3	- 0.666	5.58
		DDT	0.0643	4.66	72.5	- 0.984	219.12
	Sept 21/76	FFT	0.2006	4.44	22.1	- 0.948	62.17
		FDT	0.3393	4.99	14.7	- 0.960	82.98
		DFT	0.0505	2.30	45.7	- 0.983	205.21
		DDT	0.0944	3.72	39.4	- 0.970	114.40
	June 9/77	DFT	0.0003	- 3.81	-1.3×10^{5}	+ 0.952	67.73
	July 22/77	FFT	0.1090	3.66	33.7	- 0.925	41.88
		DFT	0.0737	3.21	43.7	- 0.755	7.95
		DDT	0.1240	7.66	61.8	- 0.979	168.29
	Sept 14/77	--	--	--	--	--	--
	Oct 19/77	FFT	0.0941	16.18	171.8	- 0.715	7.34
		FDT	0.1604	15.26	95.1	- 0.672	5.77
	Nov 23/77	DFT	0.1359	1.41	10.4	- 0.858	19.60
		DDT	0.3684	6.57	17.8	- 0.977	147.61
Nanticoke	July 14/77	FFT	0.1843	8.34	45.3	- 0.975	136.18
	Aug 23/77	--	--	--	--	--	--
	Sept 27/77	DDT	1.679	11.95	7.1	- 0.927	43.38
	Nov 16/77	FFT	0.1089	1.40	12.9	- 0.821	14.47
		FDT	0.3914	6.96	17.8	- 0.871	21.99
		DDT	0.1176	3.86	32.9	- 0.903	31.17
Bruce 'A'	July 6/77	FDT	0.0731	11.17	152.8	- 0.755	9.33
	Aug 18/77	FDT	0.0520	3.92	75.5	- 0.875	23.04
		DDT	0.0313	4.59	146.6	- 0.897	28.95
	Oct 5/77	FDT	0.0810	5.48	67.6	- 0.909	33.49
		DFT	0.0582	5.59	96.0	- 0.913	35.27
	Nov 30/77	FDT	0.0395	2.38	60.4	- 0.847	17.79
		DFT	0.0141	2.24	158.6	- 0.724	7.75
		DDT	0.0202	3.14	155.4	- 0.691	6.42

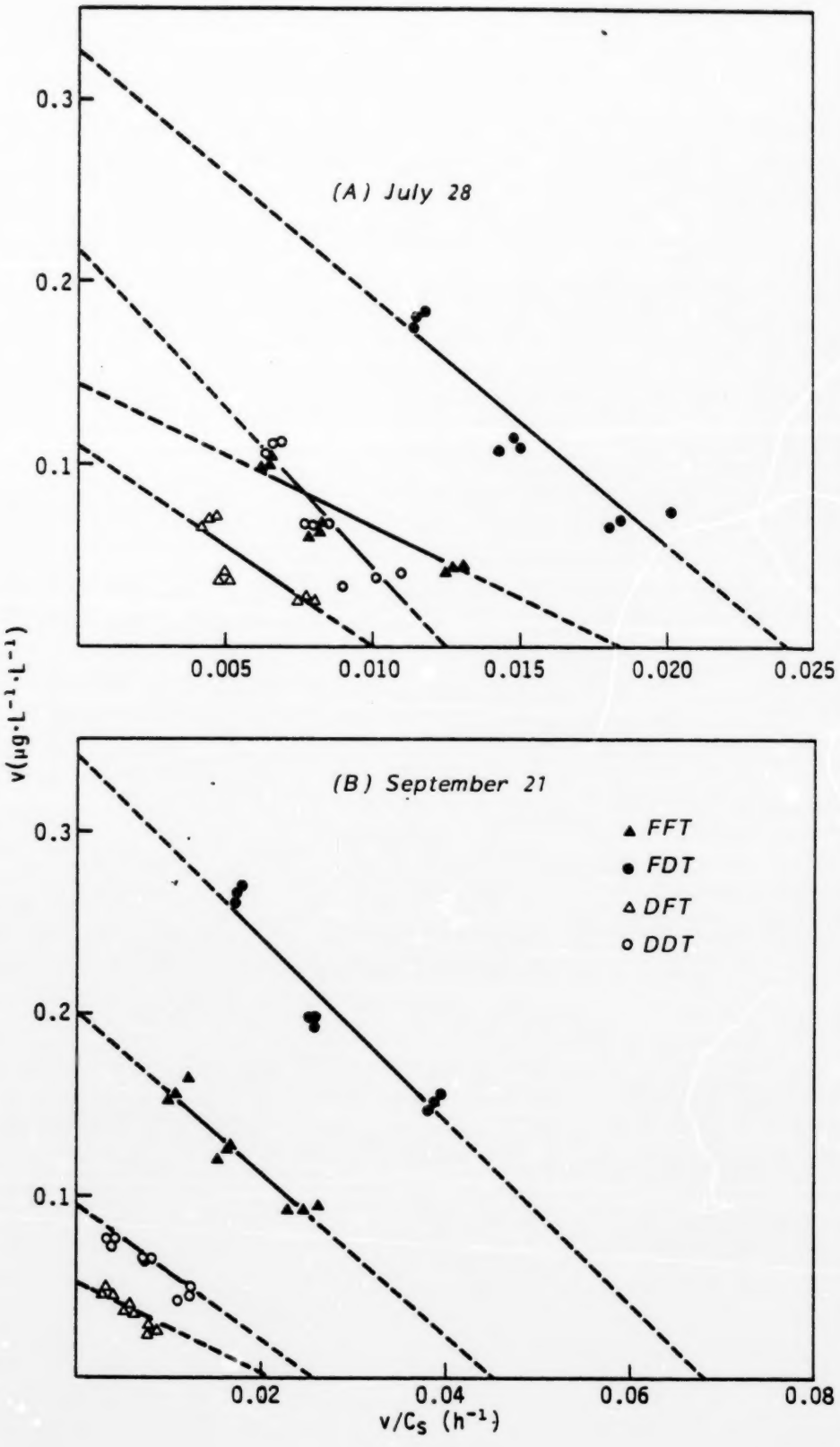

FIGURE 2
EADIE - HOFSTEE PLOTS OF GLUTAMATE UPTAKE FOR THE (A) JULY 28, 1976, AND (B) SEPTEMBER 21, 1976, PICKERING EXPERIMENTS

157988 RD

The parameter β_1 represents the possible interactive effect of condenser passage on the response to temperature elevation, being zero ($d \cdot \Delta T = 0$) if the sample had not passed through the condenser. Since the rate of glutamate assimilation is directly proportional to the added substrate concentration, the constants C_8 and C_{16} are used to express uptake at 8 and 16 $\mu g \cdot L^{-1}$, respectively, relative to the rate at 4 $\mu g \cdot L^{-1}$. The exponents α_8 and α_{16} are set to zero for sample concentrations other than 8 or 16 $\mu g \cdot L^{-1}$, respectively.

Uptake of glutamate at added substrate concentrations of 8 and 16 $\mu g \cdot L^{-1}$ relative to uptake at 4 $\mu g \cdot L^{-1}$ is shown in Figure 3. Six anomalous values, which also appeared as outliers in residual plots of the data, were indicated (circled values in figure). Not included in the figure was the data for the September 27 Nanticoke experiment in which uptake velocities were close to an order of magnitude higher than values observed in other experiments (Table 2) and their inclusion would therefore have had an inordinate influence on estimation of the proportionality constants for glutamate uptake.

Multiple linear regression analysis was performed on the logarithmic form of equation 2:

$$\ell n\, G_{i,j,k} = \ell n \mu_i + d\ell nP + \beta_0 \Delta T + \beta_1 (d\Delta T) + \alpha_8 \ell n C_8 + \alpha_{16}\, \ell n C_{16} \quad (3)$$

In samples in which no glutamate uptake occurred (v=0) a value of one was assumed. Initial parameter estimates for the model indicated a general agreement between predicted and observed values (Figure 4). The six previously identified anomalous values were again apparent (circled in figure). Also the model did not adequately predict glutamate uptake rates for the July 14 and August 23 Nanticoke experiments (boxed values in figure). On these two dates discharge temperatures of 31.0 and 32.5°C, respectively, were the highest encountered. In the July 14 experiment there was no glutamate uptake in discharge samples (points lying on ordinate in Figure 4) and a substantial reduction in activity occurred in forebay samples which were inclubated at the discharge temperature. In the August 23 experiment heterotrophy was substantially reduced following station passage and little or no increase in glutamate uptake occurred when samples were incubated at the elevated temperature of the discharge. The ΔT across the station on these two dates was 9.0 to 12.5°C, similar to many other experiments, indicating that it was total (discharge) temperature rather than the degree of temperature elevation which was critical.

Results from the model fitting, excluding the data points highlighted in Figure 4, are presented in Table 3. The model accounted for 85% of the observed variation in glutamate uptake and its representation of the data was significant ($F_{19,173} = 47.95$; $p < 0.0001$). The effects of temperature elevation and condenser passage on glutamate uptake were both significant ($p < 0.001$) while no interaction between these two factors was indicated. The parameter β_1 may therefore be deleted from the model (Equation 2). Constants of proportionality for uptake rates at 8 and 16 $\mu g \cdot L^{-1}$ compared to uptake at 4 $\mu g \cdot L^{-1}$ were also significant ($p < 0.001$) indicating that there was no change in the observed relationships between dates and locations. A doubling of glutamate concentration to 8 $\mu g \cdot L^{-1}$ caused the uptake rate to fall to 71% of its value at 4 $\mu g \cdot L^{-1}$ (Table 3). A further doubling in

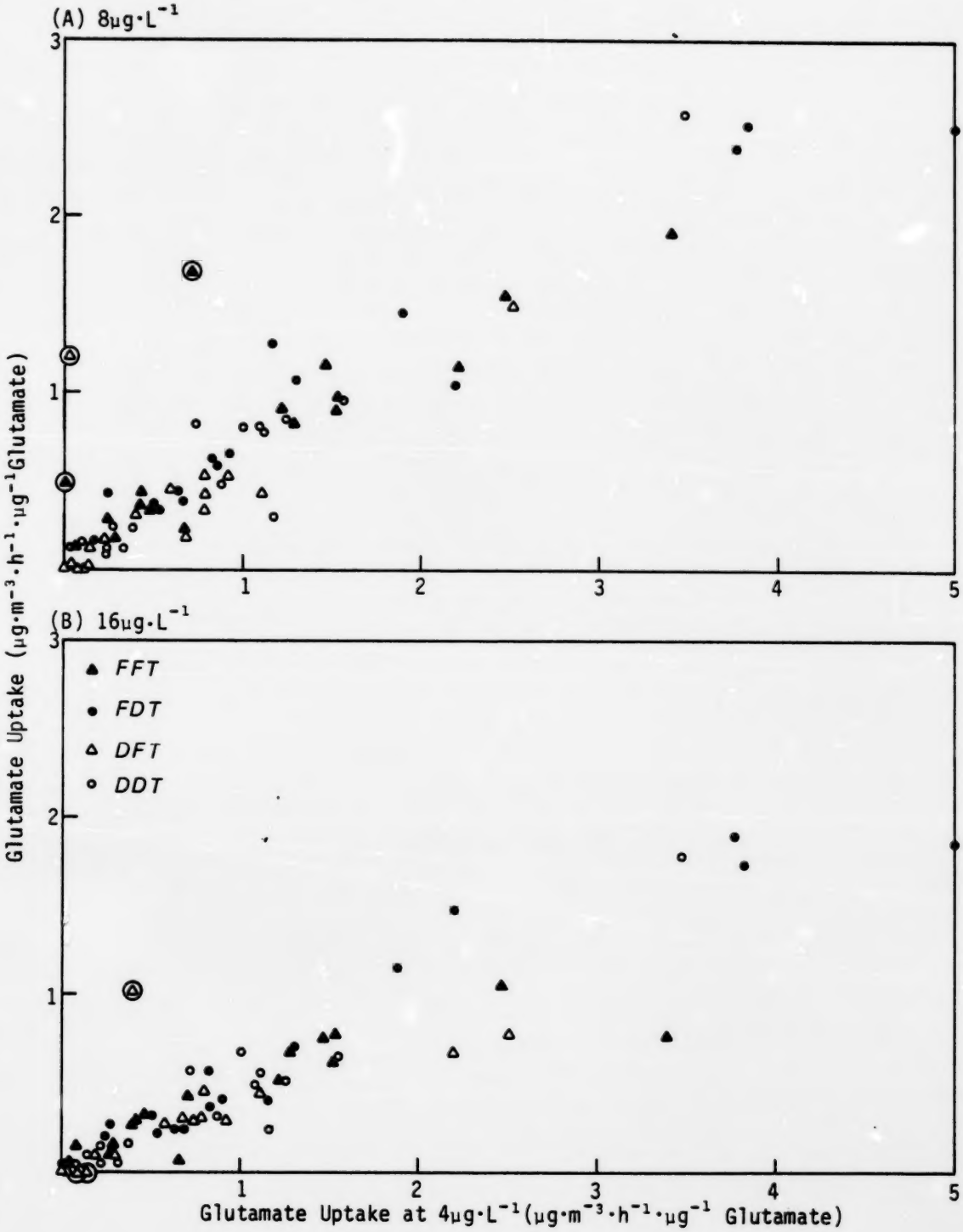

FIGURE 3

GLUTAMATE UPTAKE AT ADDED SUBSTRATE CONCENTRATIONS OF (A)8µg·L^{-1} AND (B) 16µg·L^{-1} RELATIVE TO UPTAKE AT 4µg·L^{-1}

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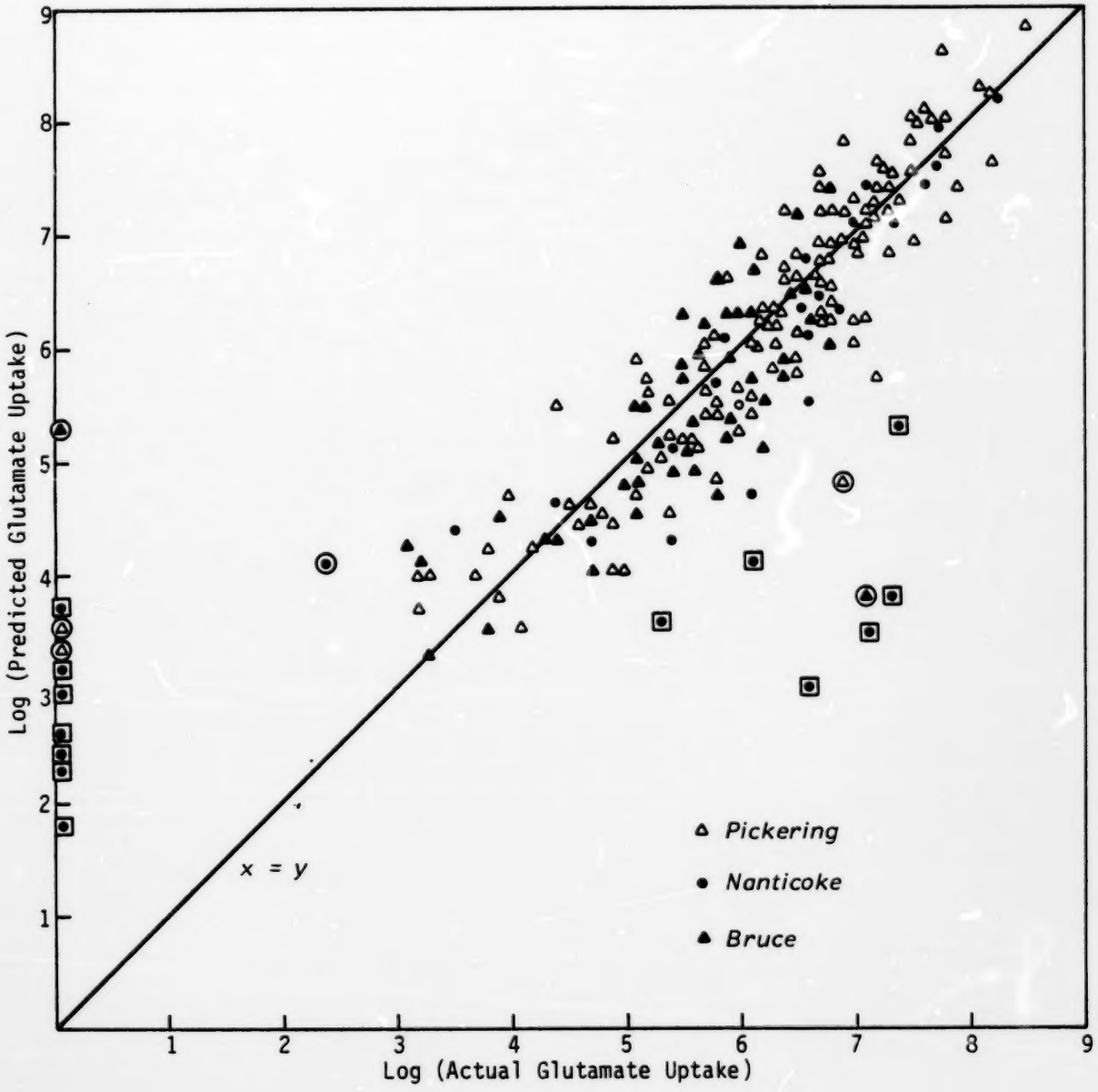

FIGURE 4

RELATIONSHIP BETWEEN OBSERVED AND PREDICTED VALUES FOR GLUTAMATE UPTAKE

157990 RD

TABLE 3

RESULTS FROM MODEL FITTING FOR GLUTAMATE UPTAKE

Source	DF	Sum of Squares	Mean Square	F-Value	P > F	R-Square	C.V.
Model *	19	196.467	10.340	47.95	0.0001	0.855	7.61
Error	154	33.209	0.216				
Corr. Total	173	229.676					
* Dates	14	142.374		47.16	0.0001		
ℓn C_{16}	1	10.559		48.96	0.0001		
ℓn C_8	1	2.965		13.75	0.0003		
ℓn P	1	27.377		126.95	0.0001		
β_0	1	13.164		61.05	0.0001		
β_1	1	0.028		0.13	0.7193		

concentration, to 16 $\mu g \cdot L^{-1}$, would be expected to lead to a reduction of 50% (ie: 71% x 71%) of the uptake rate at 4 $\mu g \cdot L^{-1}$. The estimate of 47% with 95% confidence intervals of 40 and 56% lends further credence to the model.

Glutamate activity following condenser passage averaged 43% of that occurring under ambient conditions while temperature elevation stimulated heterotrophic activity providing the total (discharge) temperature did not exceed 30°C (Table 4). Glutamate uptake increased by approximately 6.4% for each degree Celsius increase in temperature. For a temperature rise of 10°C glutamate uptake increased by $e^{10\beta_0}$ or approximately 1.9 times. The 95% confidence intervals indicated relative consistency in observed station passage and temperature effects. The representativeness of the model with respect to the Nanticoke station is uncertain, however, since only one of four experiments conducted at this site was included in the analysis.

Assessment of Net Effect of Entrainment on Heterotrophic Production

Quantification of the effects of station passage and temperature elevation on glutamate uptake provided an opportunity to assess the effect of once-through cooling on heterotrophic productivity in affected waters. At the Nanticoke and Bruce stations cooling water is withdrawn from submerged intakes and bacterial populations in source and receiving water bodies may differ. Pickering GS 'A' which has both a surface intake and discharge was therefore selected for assessment.

Capacity operation of Pickering, providing a cooling water flow of 112 $m^3 \cdot s^{-1}$, a ΔT at 10°C and a maximum discharge temperature of less than 30°C, conditions typical to the operation of this station, were assumed. Chlorine or other biocides are not used for the prevention of condenser biofouling. The area of the Pickering thermal plume, for incremental 1°C isotherms, was determined using empirical relationships between plume size and operating/hydrological conditions as presented by Arajs (1980). Estimated median sized plumes at depths of 0.3 and 1.5 m were considered representative of the 0 to 1 m and 1 to 2 m portions of the water column respectively (Table 5). This would represent a plume of intermediate size based on a variety of plume configurations, being typical of an offshore spreading plume, confined, except in the nearfield area of the discharge, to the upper (<2 m depth) water strata.

Dispersion of pump entrained organisms following discharge was described by a simple heat balance equation (Grieve et al 1977):

$$C = (t - t_a)/(t_o - t_a) \quad (4)$$

where C is the proportion of pump entrained organisms at point (x, y) in the plume. The temperature of water at point (x,y) in the plume, at the point of discharge and in ambient lakewater are represented by t, t_o and t_a respectively. Relative proportions

TABLE 4

Parameter Estimates For the Glutamate Uptake Model[1]

Parameter	Description	Estimate	95% Confidence Intervals Lower	Upper
C_8	Proportionality Constant ($8\ \mu g \cdot L^{-1}/4\ \mu g \cdot L^{-1}$)	0.707	0.598	0.837
C_{16}	Proportionality Constant ($16\ \mu g \cdot L^{-1}/4\ \mu g \cdot L^{-1}$)	0.474	0.400	0.562
P	Condenser Passage Effect	0.434	0.359	0.525
β_o	Temperature (1°C) Effect	0.064	0.041	0.087
$e^{10\beta_0}$	Effect of a 10°C Temperature Increase	1.899	1.504	2.398

[1] $G_{i,j,k} = \mu_i \cdot P^d \cdot e^{\beta_0 \Delta T} \cdot C_8^{\alpha_8} \cdot C_{16}^{\alpha_{16}}$

TABLE 5

Area and Volume of the Pickering Thermal Plume (Median for 4 Unit Operation), Glutamate Uptake Rates within 1°C Isotherms and Net Glutamate Assimilation within the Thermal Plume

Isotherm-°C Above Ambient	Glutamate Uptake Rate ($\mu g.L^{-1}.h^{-1}$)			Plume Area (Hectares)			Volume of Isotherm $10^3 m^3$	Net Assimilation $g.h^{-1}$
	Discharge Population	Natural Population	Net Uptake at Isotherm	0-1 m Depth	1-2 m Depth	Total		Ambient / Plume
10	0.082	(0.190)	0.082	2.3	<1	2.4	24	2.0
9	0.077	0.178	0.087	4.2	1.2	5.4	30	2.6
8	0.072	0.167	0.091	9.0	2.3	11.3	59	5.4
7	0.067	0.157	0.094	25.0	4.5	29.5	180	17.0
6	0.063	0.147	0.097	55.0	6.8	61.8	320	31.0
5	0.059	0.138	0.099	75.0	15.0	90.0	280	28.0
4	0.056	0.129	0.100	120.0	45.0	165.0	750	75.0
3	0.052	0.121	0.100	170.0	120.0	290.0	1300	130.0
2	0.049	0.114	0.101	300.0	220.0	520.0	2300	232.0
1	0.046	0.107	0.101	500.0	350.0	850.0	3300	333.0
Ambient	(0.043)	0.100	0.100	-	-		8543	854 / 856

of pump and plume entrained organisms within the plume were therefore assumed to result from the uniform hydrological mixing of cooling and receiving waters.

Density (biomass) of bacterioplankton in the vicinity of Pickering was considered to be uniform with no increase or decrease in biomass within the thermal plume. Velocity of glutamate uptake under natural conditions was arbitrarily chosen to be 0.100 $\mu g \cdot L^{-1} \cdot h^{-1}$. From the previously derived model (Table 4) uptake by discharge populations under ambient temperature conditions was 0.043 $\mu g \cdot L^{-1} \cdot h^{-1}$. For a given temperature increase (ΔT) within 1°C isotherms the stimulation in glutamate activity for both the natural and discharge populations was equal to $e^{\beta_0 \Delta T}$ with $\beta_0 = 0.064$.

In the immediate discharge at temperatures of 5 to 10°C above ambient there was a net reduction in the rate of glutamate uptake compared to uptake under natural conditions (Table 5). This area represents about 10% of the total plume volume. A slight stimulation of heterotrophic activity was apparent on the outer margin of the plume at temperatures 1 to 2°C above ambient. Overall there was no indication of a net change in heterotrophic activity within the plume (856 $\mu g \cdot h^{-1}$) compared to an equal volume of water under ambient conditions (854 $\mu g \cdot h^{-1}$). However, the assumption of no net increase in bacterial biomass within the plume may be considered conservative in that stimulated synthesis of cellular carbon, particularly among plume entrained organisms, was indicated. Given that bacterial generation times may be less than the transit time (~4 h) required for discharged cooling water to reach ambient lakewater temperature, some increase in bacterial biomass and a concomitant increase in heterotrophic production in the periphery of the plume and in waters contiguous to the plume could be expected. This increase would be more pronounced if the mechanical effects of station passage were less severe than observed in the present study.

At stations such as Pickering, which are located on large open water bodies and where extensive vertical and horizontal mixing exists, the effect of once-through cooling is likely to be relatively localized. On small enclosed systems, however, basin wide alteration of mineralization processes may exist. Hillbricht-Ilkowska and Zdanowski (1978), for example, in a study of several Polish cooling water lakes receiving various levels of thermal enrichment, found increased efficiency in the utilization of autochthonous resources.

CONCLUSIONS

1. Heterotrophic uptake of glutamate in cooling waters was reduced approximately 57% as a result of mechanical stress encountered during station passage.

2. Temperature elevation increased the rate of glutamate uptake by approximately 6.4% for each degree Celsius increase in temperature. For a 10°C rise in temperature, glutamate uptake increased by approximately 1.9 times.

3. Station passage did not affect the response of bacteria to temperature elevation.

4. Assessment of the effect of once-through cooling at Pickering GS 'A' on heterotrophic productivity in affected waters indicated that there was a net reduction in the rate of glutamate uptake in the immediate discharge (10% of total plume volume) compared to uptake under natural conditions. This reduction was offset, however, by stimulated activity in the peripheral area of the plume. If reduction in heterotrophic activity was less than indicated (57%) or if stimulated activity resulted in an increase in bacterial biomass then an overall increase in productivity could be expected particularily in peripheral areas of the plume and contiguous waters.

ACKNOWLEDGEMENT

The model relating station passage and temperature effects to glutamate uptake was formulated and analyzed by Mr. C.J. Schwarz of the Operations Research Department (Ontario Hydro Research Division Report 82-278-K).

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APPENDIX

Summary of Glutamate Uptake ($\mu g \cdot m^{-3} \cdot h^{-1} \cdot \mu g$ ^{14}C-Glutamate x 10^2)
For Added Substrate Concentrations of 4, 8 and 16 $\mu g \cdot L^{-1}$
Mean (G) and Standard Deviation (S) Given For Triplicate Samples

OBS	LOCATION	DATE	TYPE	TEMP	G4	S4	G8	S8	G16	S16
1	P	15JUL76	FF	7.5	271	26	182	40	98	5
2	P	15JUL76	FD	17.0	534	166	345	15	224	17
3	P	15JUL76	DF	7.5	144	128	25	26	0	0
4	P	15JUL76	DD	17.0	93	101	141	40	47	15
5	P	28JUL76	FF	12.3	1284	21	821	25	680	23
6	P	28JUL76	FD	22.5	1882	112	1472	30	1164	19
7	P	28JUL76	DF	12.3	787	23	532	13	466	12
8	P	28JUL76	DD	22.5	1008	104	810	31	685	24
9	P	12AUG76	FF	17.5	1527	190	978	41	779	95
10	P	12AUG76	FD	27.5	.	.	1727	40	1311	12
11	P	12AUG76	DF	17.5	788	171	432	9	305	17
12	P	12AUG76	DD	27.5	1079	184	811	19	482	3
13	P	03SEP76	FF	16.0	1211	151	918	18	526	19
14	P	03SEP76	FD	24.0	1277	94	1083	32	687	39
15	P	03SEP76	DF	16.0	677	56	187	7	246	10
16	P	03SEP76	DD	24.0	874	35	478	10	303	5
17	P	21SEP76	FF	16.3	2460	54	1574	49	1063	61
18	P	21SEP76	FD	25.0	3823	83	2527	10	1732	30
19	P	21SEP76	DF	16.3	893	24	519	8	297	6
20	P	21SEP76	DD	25.0	1228	53	835	8	489	10
21	P	09JUN77	FF	9.0	671	14	240	17	57	8
22	P	09JUN77	FD	17.0	1151	130	1285	21	409	319
23	P	09JUN77	DF	9.0	43	64	24	1	0	0
24	P	09JUN77	DD	17.0	317	144	110	13	40	7
25	P	22JUL77	FF	9.0	1514	24	942	35	621	9
26	P	22JUL77	FD	18.0	2185	41	1040	27	1489	23
27	P	22JUL77	DF	9.0	1100	61	428	247	448	9
28	P	22JUL77	DD	18.0	1091	16	806	13	564	20
29	P	14SEP77	FF	17.3	80	7	140	14	165	14
30	P	14SEP77	FD	24.5	163	97	173	4	278	8
31	P	14SEP77	DF	17.3	65	13	27	12	59	8
32	P	14SEP77	DD	24.5	219	57	117	5	139	2
33	P	19OCT77	FF	9.8	469	6	352	28	331	9
34	P	19OCT77	FD	19.0	814	73	620	13	586	56
35	P	19OCT77	DF	9.8	404	13	319	8	1014	50
36	P	19OCT77	DD	19.0	1158	30	309	22	219	13
37	P	23NOV77	FF	7.8	3395	165	1912	52	778	24
38	P	23NOV77	FD	16.7	4976	173	2506	172	1853	25
39	P	23NOV77	DF	7.8	2508	42	1498	4	776	41
40	P	23NOV77	DD	16.7	3469	63	2591	70	1810	70
41	N	14JUL77	FF	22.0	1460	35	1106	8	756	19
42	N	14JUL77	FD	31.5	229	95	441	10	210	12
43	N	14JUL77	DF	22.0	0	0	0	0	0	0
44	N	14JUL77	DD	31.5	0	0	0	0	0	0

APPENDIX (cont'd)

OBS	LOCATION	DATE	TYPE	TEMP	G4	S4	G8	S8	G16	S16
45	N	23AUG77	FF	20.0	700	6	1707	26	457	37
46	N	23AUG77	FD	32.5	906	785	673	20	414	230
47	N	23AUG77	DF	20.0	108	67	11	16	0	0
48	N	23AUG77	DD	32.5	224	46	82	5	32	28
49	N	27SEP77	FF	18.8	7075	307	5280	1543	3461	43
50	N	27SEP77	FD	28.8	11044	227	5569	194	.	.
51	N	27SEP77	DF	18.8	6260	312	4444	1364	3166	107
52	N	27SEP77	DD	28.8	9830	227	8914	227	5817	206
53	N	16NOV77	FF	10.0	2203	47	1160	16	680	64
54	N	16NOV77	FD	20.5	3760	31	2405	40	1902	25
55	N	16NOV77	DF	10.0	787	15	337	22	300	18
56	N	16NOV77	DD	20.5	1552	26	964	20	652	19
57	B	06JUL77	FF	21.0	0	0	486	32	47	9
58	B	06JUL77	FD	24.0	478	51	357	18	331	6
59	B	06JUL77	DF	21.0	24	42	1205	907	28	6
60	B	06JUL77	DD	24.0	23	41	122	4	44	1
61	B	18AUG77	FF	17.0	248	17	301	17	177	2
62	B	18AUG77	FD	21.0	627	68	451	14	241	8
63	B	18AUG77	DF	17.0	164	99	154	6	77	2
64	B	18AUG77	DD	21.0	367	28	232	5	165	2
65	B	05OCT77	FF	12.3	424	25	453	14	300	11
66	B	05OCT77	FD	20.0	830	14	658	6	371	12
67	B	05OCT77	DF	12.3	592	19	451	41	270	16
68	B	05OCT77	DD	20.0	717	5	855	13	583	29
69	B	30NOV77	FF	6.3	414	17	377	10	162	8
70	B	30NOV77	FD	10.7	650	56	379	6	238	9
71	B	30NOV77	DF	6.3	223	9	162	12	83	4
72	B	30NOV77	DD	10.7	270	30	210	27	113	8